Advanced Instrumentation for Polar Research

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National Science Foundation :: Kansas Technology Enterprise Corporation :: National Aeronautics and Space Administration

The University of Kansas | The Ohio State University | Pennsylvania State University
The University of Maine | Elizabeth City State University | Haskell Indian Nations University

Centre for Polar Observation and Modelling | University of Copenhagen
Technical University of Denmark | Antarctic Climate & Ecosystems CRC

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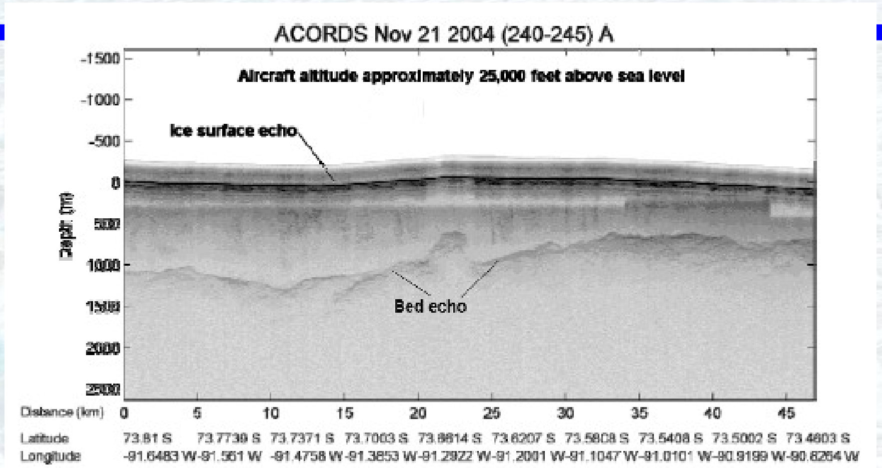
Outline

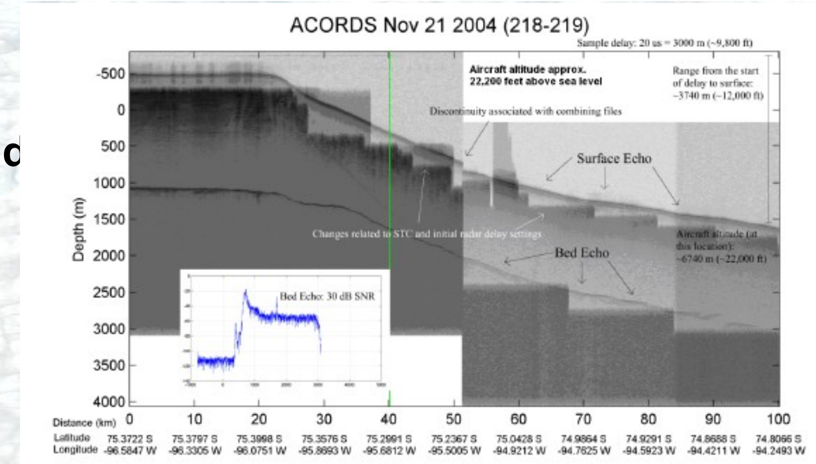
- Introduction and Background
- Systems and sample field and laboratory results
  - Radar Sounder/Imager
  - Ultra wideband Radar
    - 2.5 -7 GHz
  - Ku-band radar altimeter

Sensor	Freq/BW	Purpose
Radar Sounder/Imager	195 /30 MHz	Ice thickness Bed topography Basal conditions Internal Layers
Microwave Ultra-wideband Radar	2.5-7 GHz	Snow thickness over sea ice and internal layers in firn
Radar Altimeter (RA)	15/4 GHz	Ice-surface elevation Accumulation rate Snow thickness

Introduction—Ice Thickness

- **Radar Sounding of glaciers is well established.**
- **Major challenges are**
  - **sounding of fast-flowing glaciers and ice-sheet margins**
  - **High-altitude measurements**
- **Ice thickness is a key to developing models to predict future sea level rise**
- **Synthetic Aperture Radar (SAR) and Array processing to reduce clutter**
  - **Sound ice**
- **Image ice-bed interface**

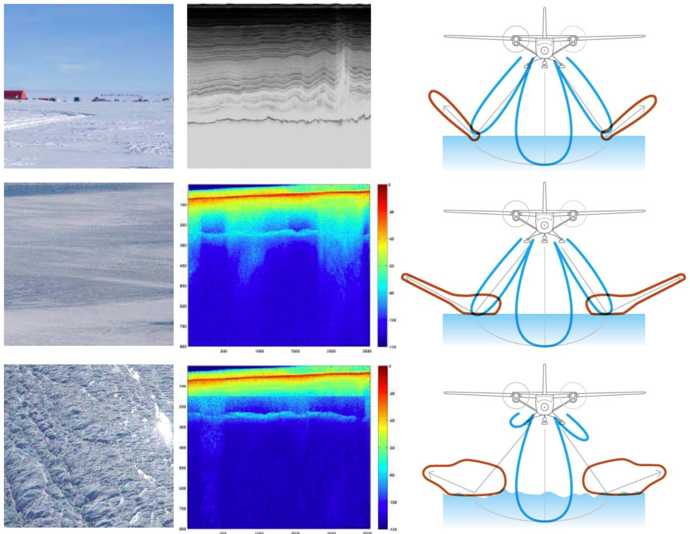




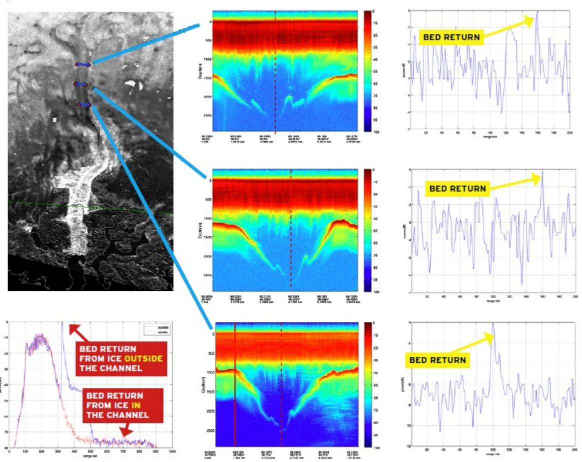
Introduction — Ice Thickness

- SAR imaging of ice-bed
- Sounding of fast-flowing glaciers
  - A major challenge in radio glaciology
- Extremely low-range sidelobes

Clutter Problem & **SOLUTION**



Jakobshavn Channel → ACROSS

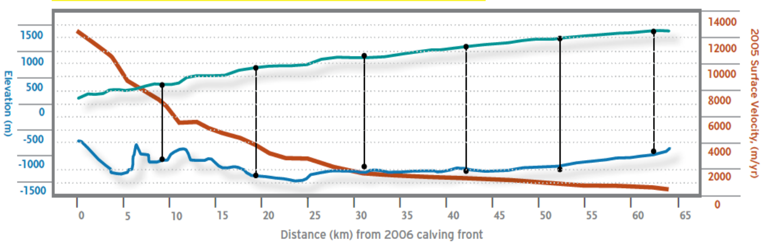


Each echogram is accompanied by an example A-scope (amplitude vs. range cells) to its right and a sample location used to generate the A-scope is shown by a red dashed line in the echograms.

A-scopes show bottom returns are very weak (2-3 dB above the noise), but detectable. The A-scope on the bottom left compares return signals from the glacier bed inside and outside the channel.

The 1.5-km thick additional ice in the channel resulted in a total loss of about 70 dB.

Jakobshavn Isbrae Along-Channel Velocity (2005) and Bed & Surface Elevation (2006)



SURFACE ELEVATION (NASA ATM, W. Krabill, and B. Csatho)
BED TOPOGRAPHY
SURFACE VELOCITY (provided by Ken Jezek and Ian Joughin)

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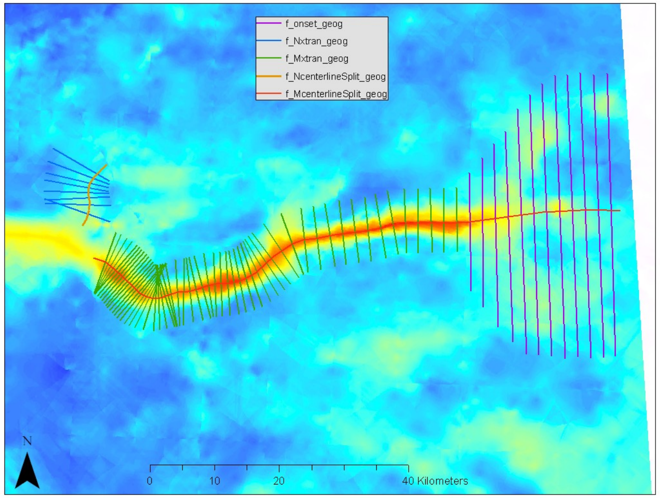
Large Errors in Flux Estimation km^3/yr

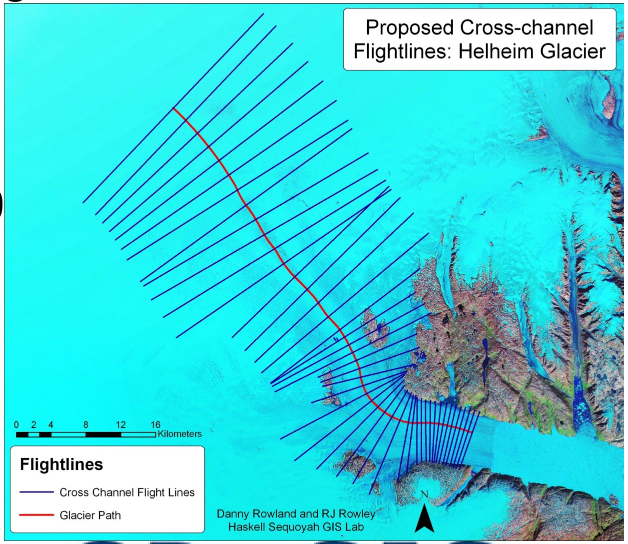
Year	South	North	Total
1985	25.3 ± 3.5	2.7 ± 0.5	28.0 ± 4.0
1995	25.3 ± 3.1	2.6 ± 0.5	27.9 ± 3.6
2000	32.7 ± 4.1	4.6 ± 0.9	37.3 ±5.0
2005	34.2 ± 4.7	6.2 ± 1.4	40.4 ± 6.0

Accurate ice thickness and bed topography information are required

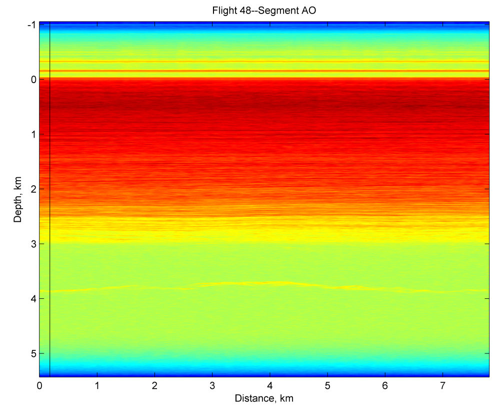
Dense grid over three key glaciers

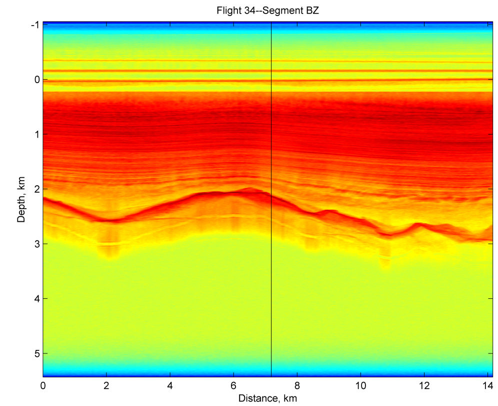


March-April 09



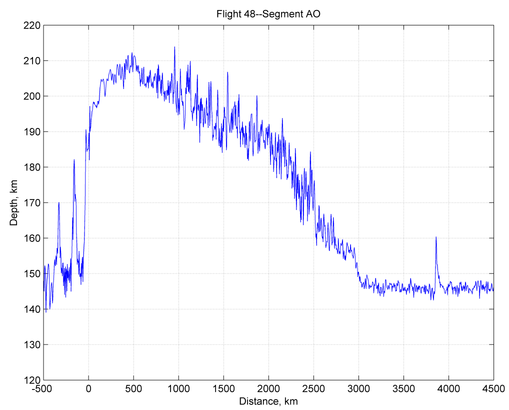
Introduction— Need for Improved Radar



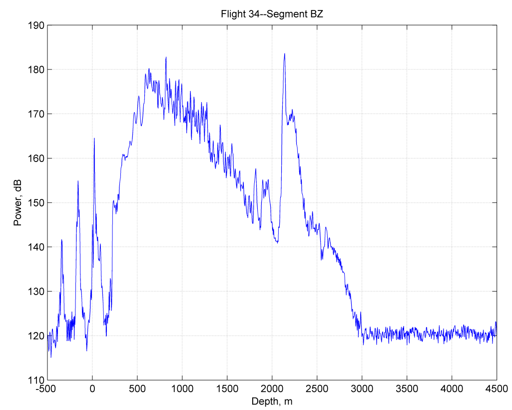


$G \propto N^2$

$G_T G_R \sim 20$ dB



Results from GAMBIT project



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Multichannel Coherent Radar Sounder/Imager (MCoRDS/I)

- Low- and high-altitude operation
- 8-Channel complex waveform generator
  - Transmit antenna pattern with 30-35 db sidelobes
- 8-Channel receiver and digitizer
  - Receive antenna pattern with 30-35 dB sidelobes
  - Nadir beam to sound ice
  - Off-nadir beams to image ice-bed interface
- 30-50 dB higher sensitivity
- Range sidelobes – 70 dB or lower
- Antenna sidelobes ~ 70 dB or lower for two way

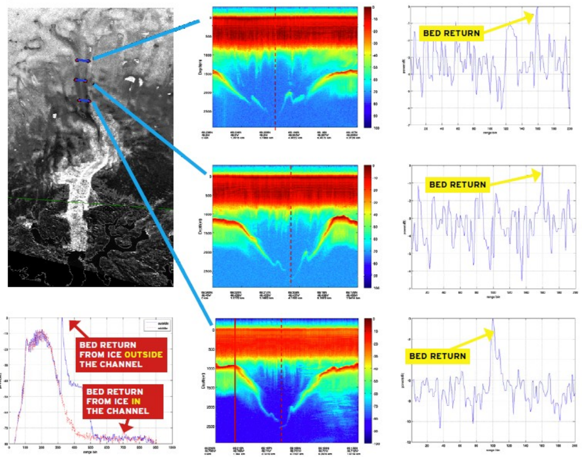
System Parameters

Parameter	Value	Units
Center frequency / bandwidth	195 / 30	MHz
Peak transmit power	800	W
Transmit pulse duration	2-30	μs
Pulse repetition frequency	7.5/10	kHz
Number of antennas in array	5	
Range of operating altitudes	0.5 to 10	km
Nominal ground speed	250	m/s
Maximum ice thickness	5	km
Vertical resolution (in ice)	2.8	m
Number of receive channels	5	
Recording data rate	220	MB/s
On-board data storage capacity	5	TB

Radar Sounder/Imager

- SAR imaging of ice-bed
- Sounding of fast-flowing glaciers
  - A major challenge in radio glaciology
- Extremely low-range sidelobes

Jakobshavn Channel ⟶ ACROSS



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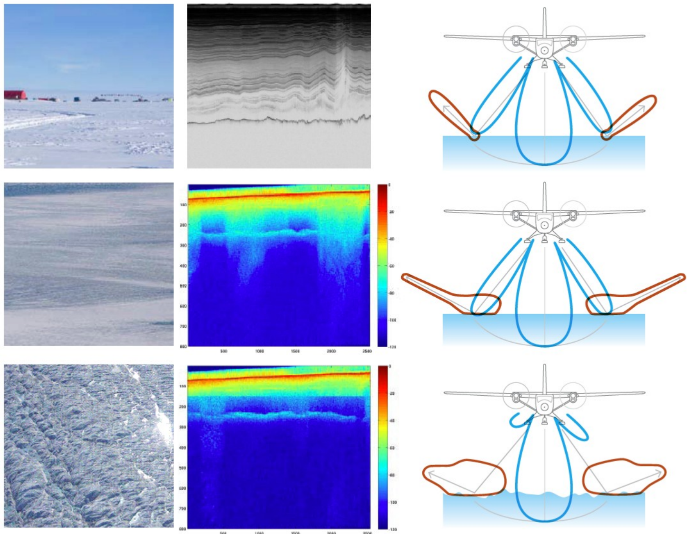
Clutter Problem & SOLUTION



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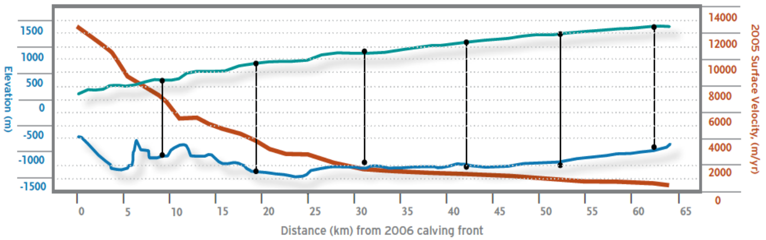

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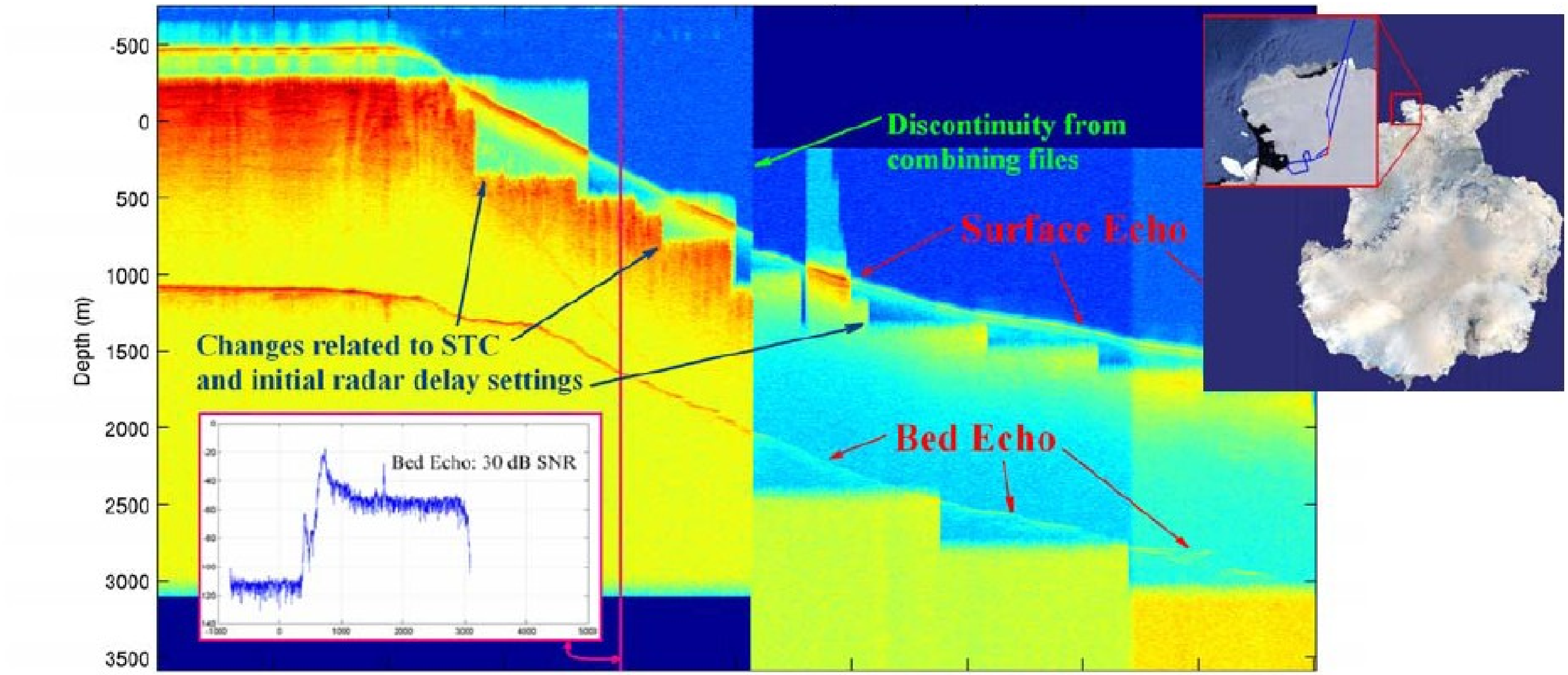
High Altitude



Distance (km)	0	10	20	30	40	50	60	70	80	90	100
Latitude	75.372 S	75.38 S	75.4 S	75.356 S	75.299 S	75.237 S	75.043 S	74.986 S	74.929 S	74.869 S	74.807 S
Longitude	-96.585 W	-96.331 W	-96.075 W	-95.869 W	-95.681 W	-95.5 W	-94.921 W	-94.762 W	-94.592 W	-94.421 W	-94.249 W
Altitude (ft)	3854	3870	3858	6659	9459	12025	17697	19101	19950	20935	22028

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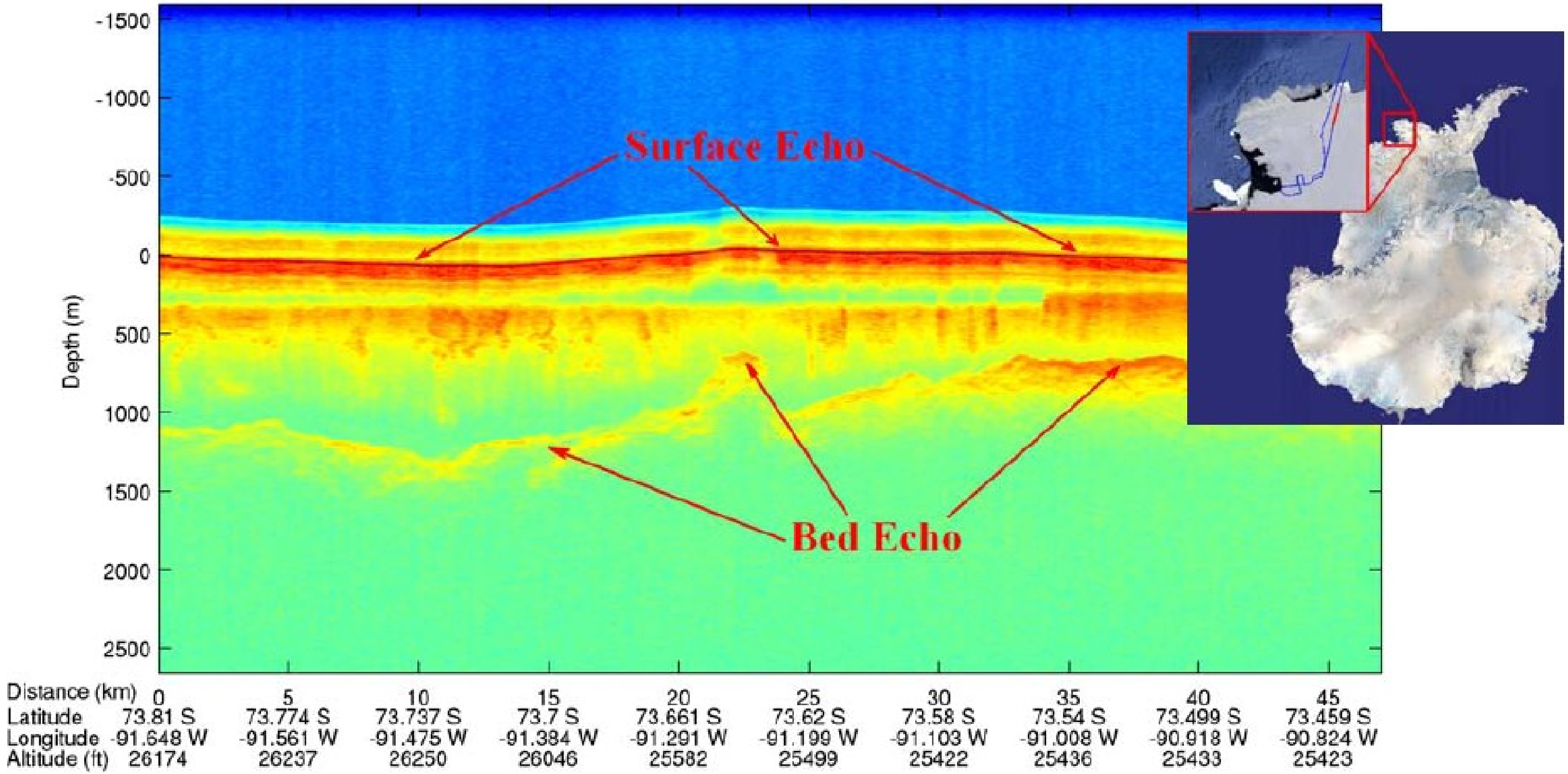
Results from high altitude



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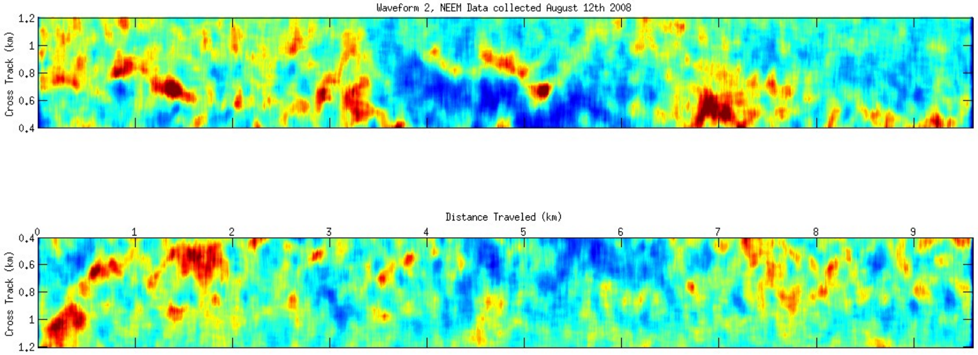
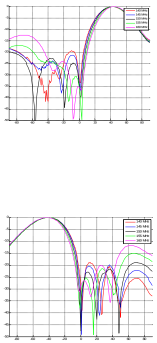
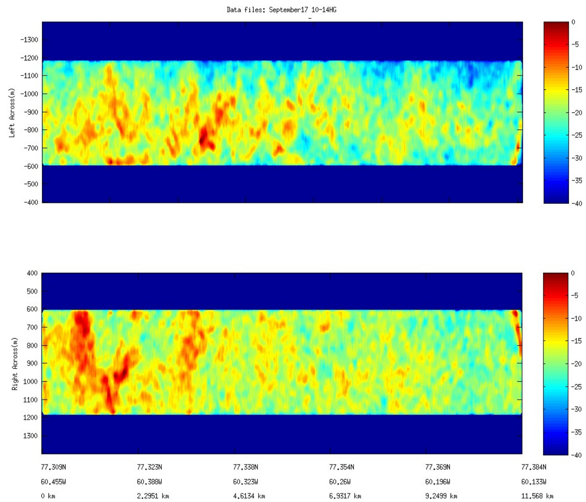
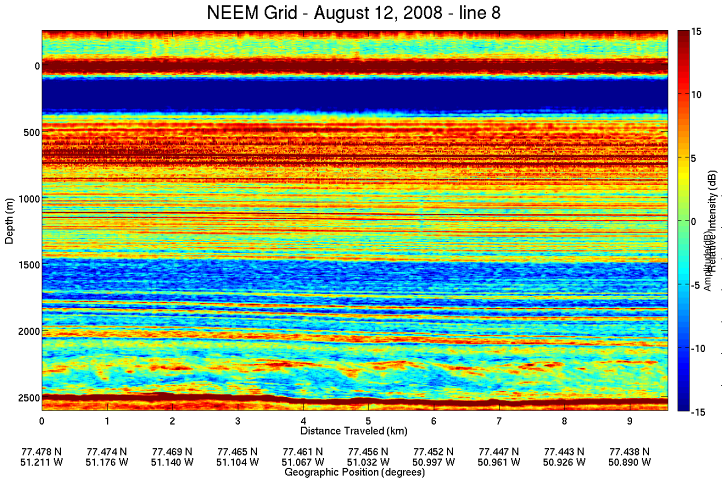
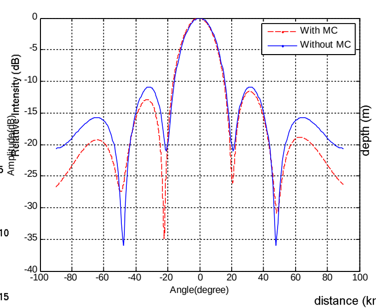
SAR Imaging of Ice Bed

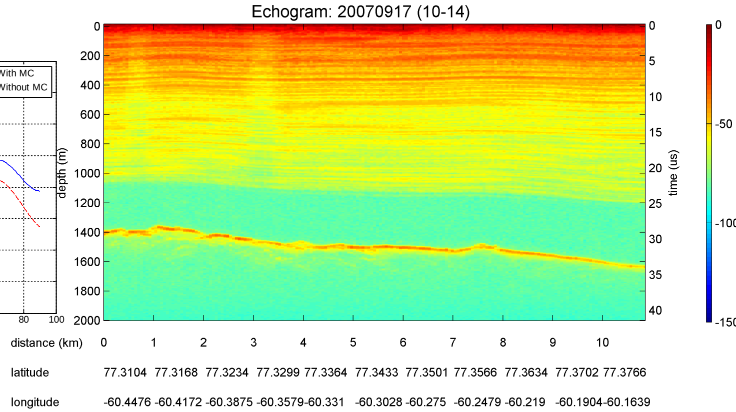












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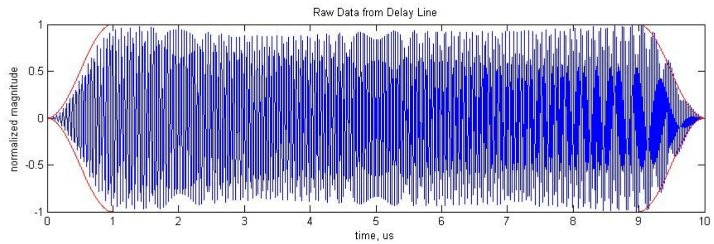
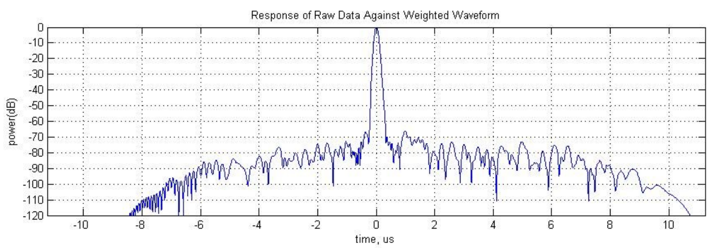
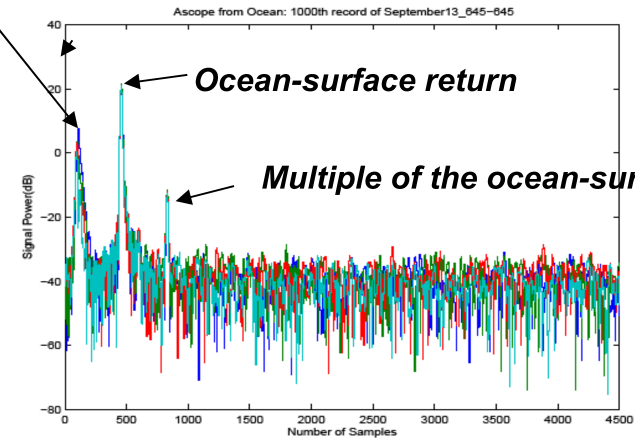
Low-Range Sidelobes



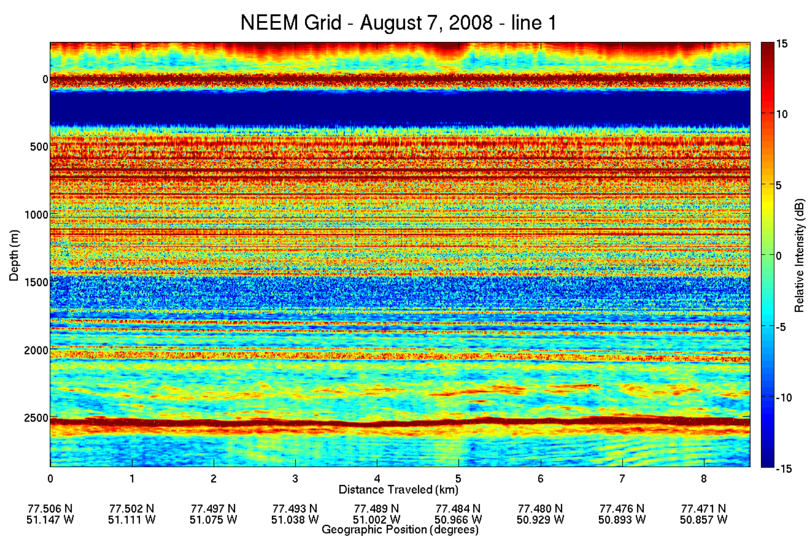


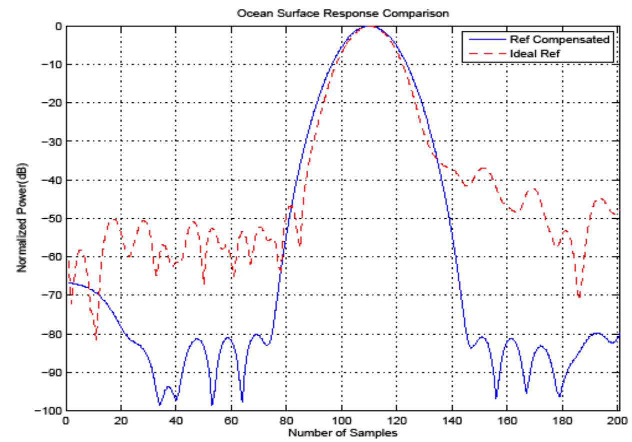
Feedthrough signal



Ocean-surface return

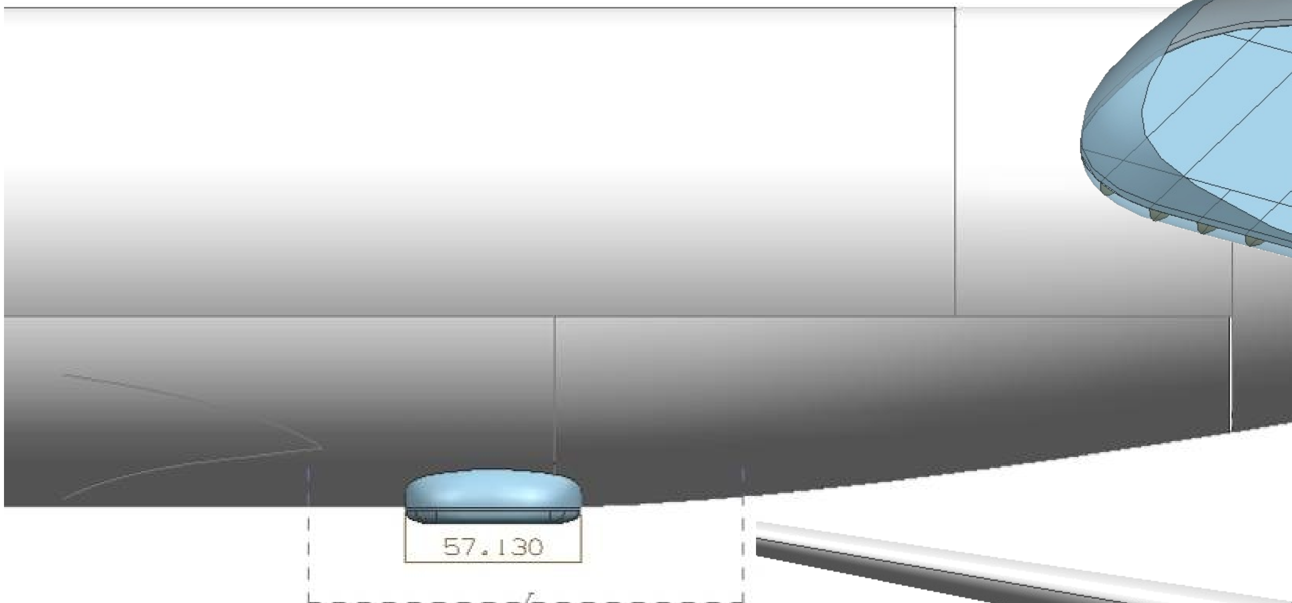
Multiple of the ocean-surface

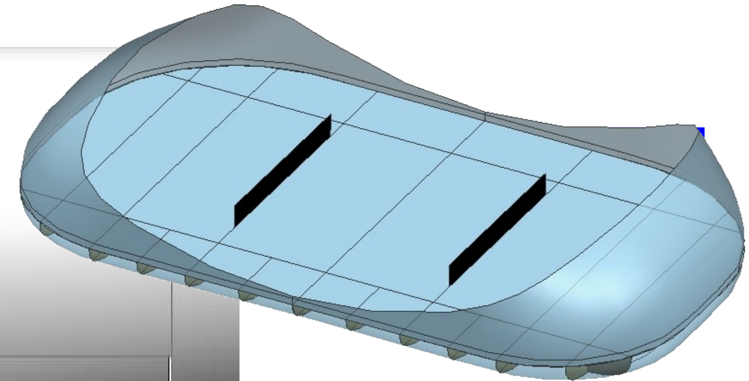


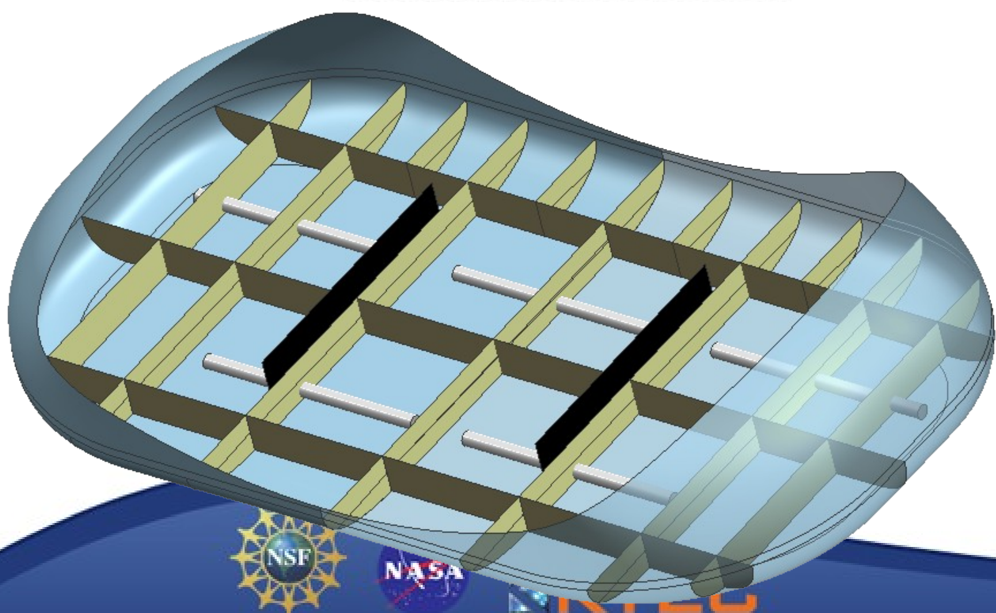


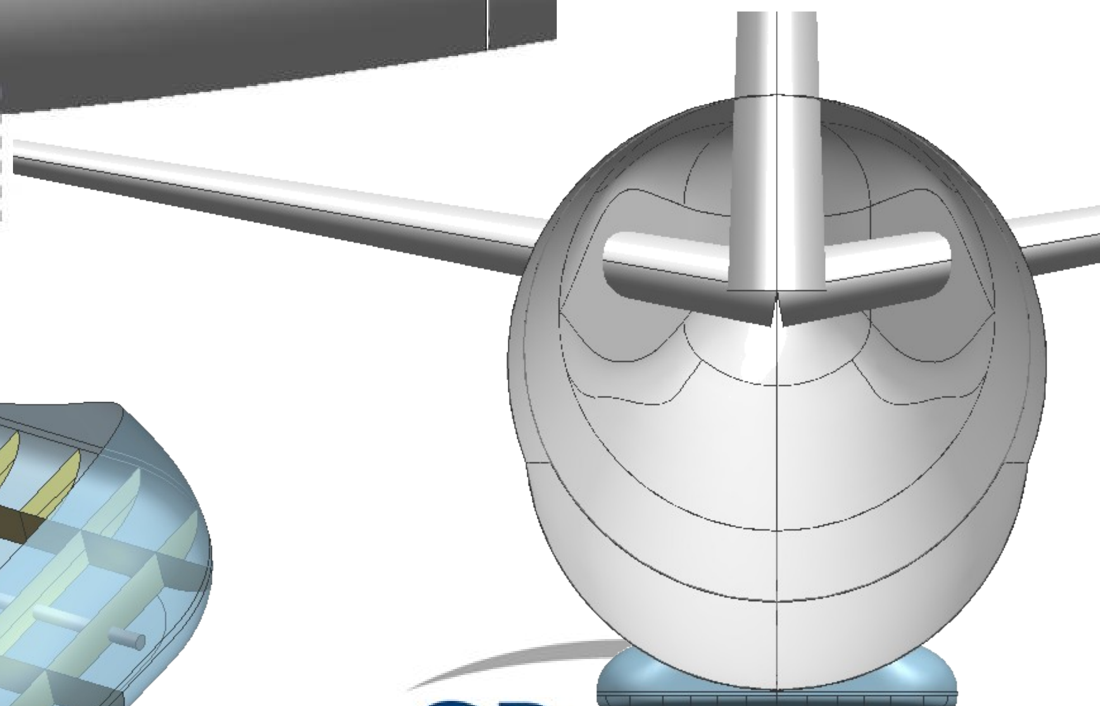
ompressed ocean-surface return

Depth sounder fairing development









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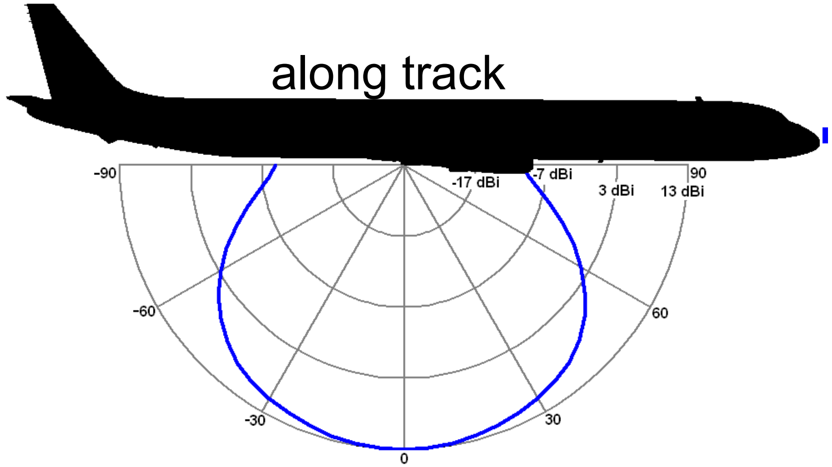
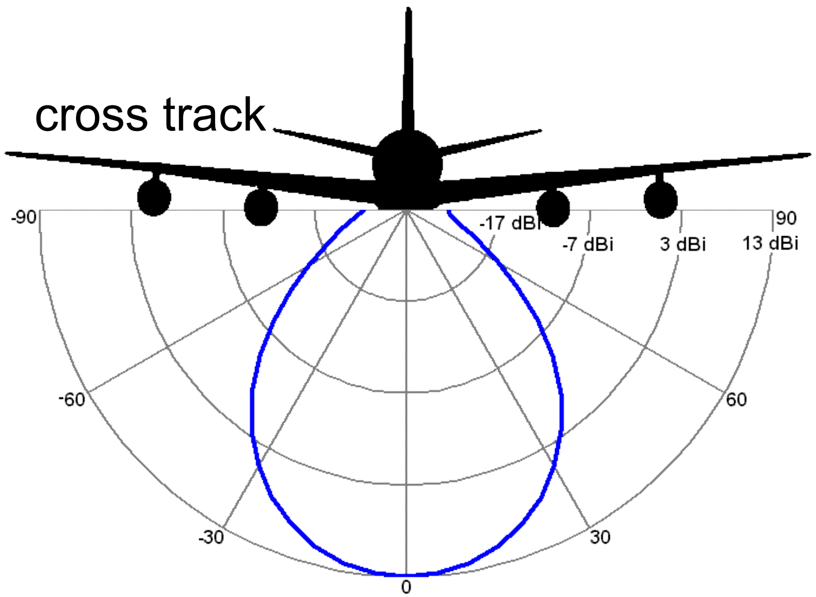
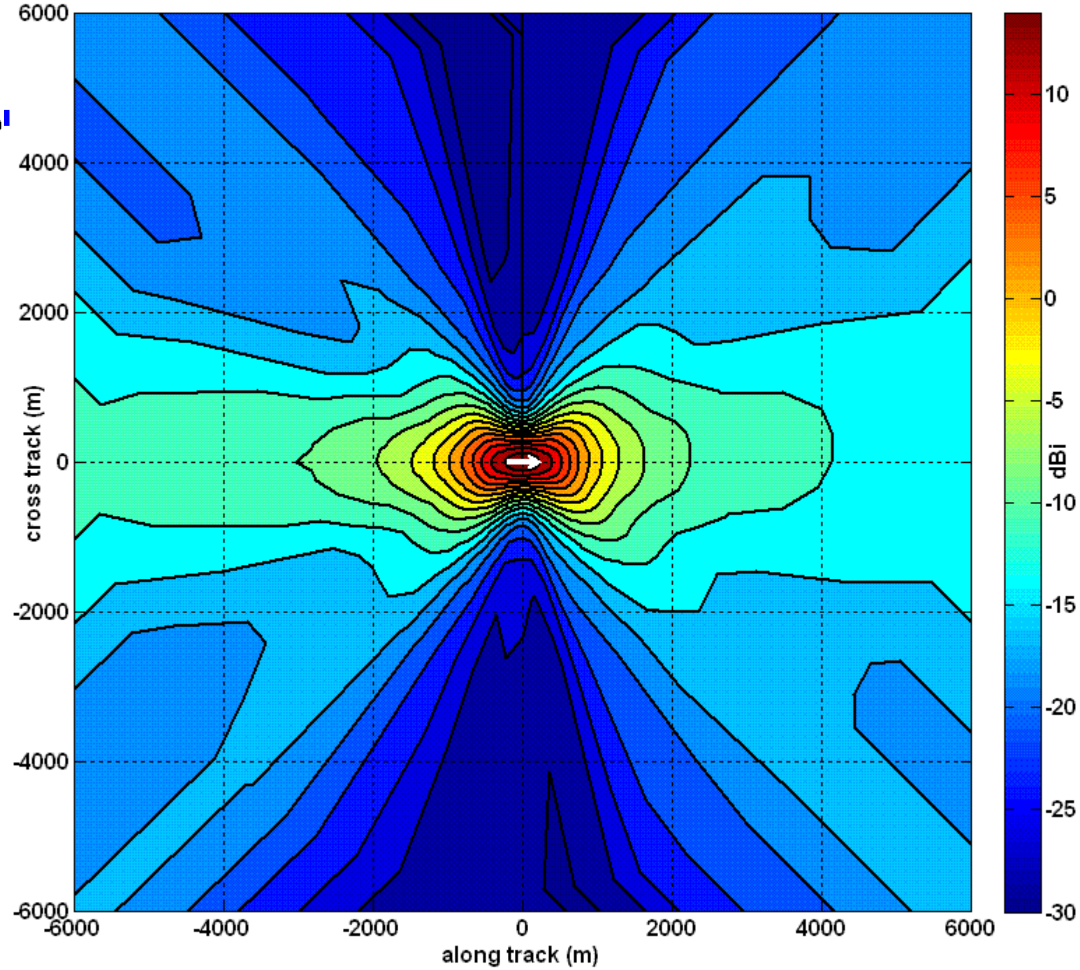
Depth sounder antenna & fairing development



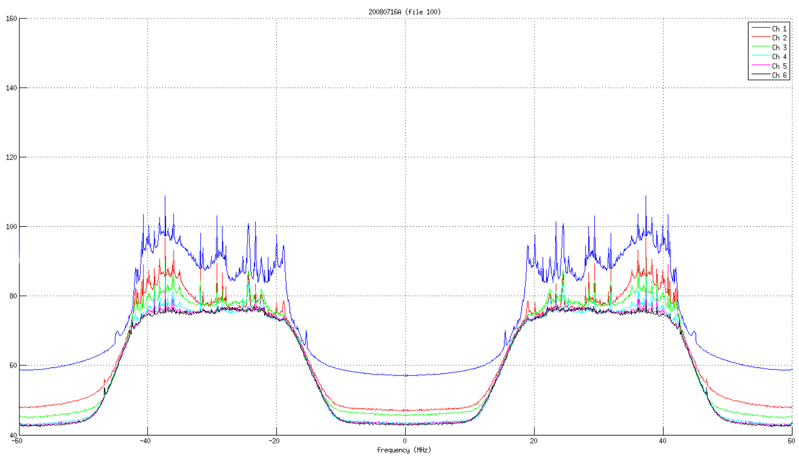


Simulated along- and cross-track antenna pattern with Blackmann weights.

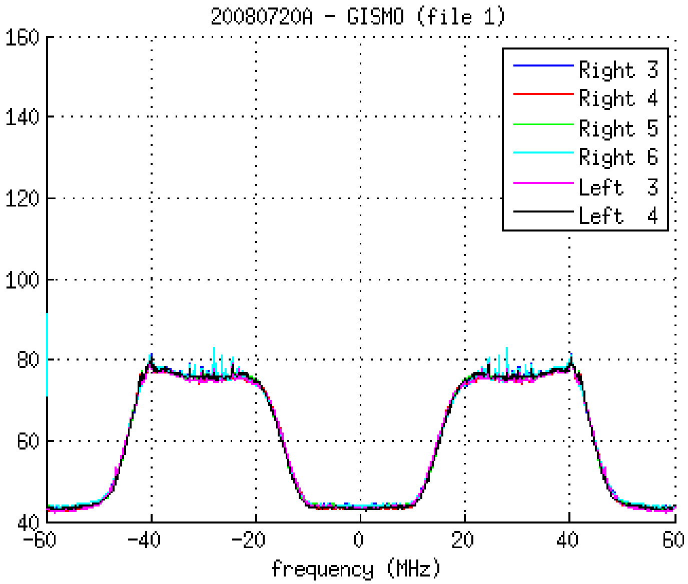


Simulated antenna pattern with Blackmann weights projected onto the ground at 195 MHz for aircraft altitude of 500 m AGL.

RFI

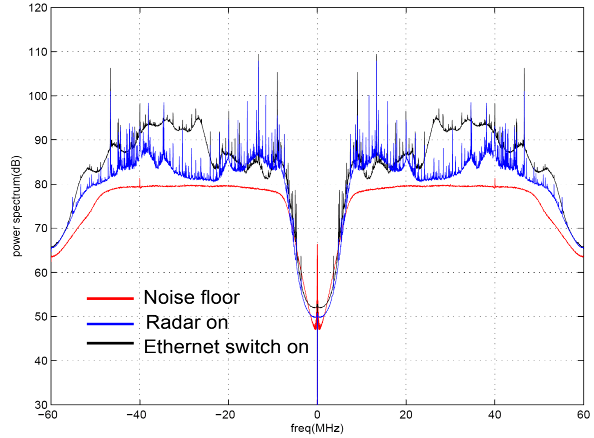


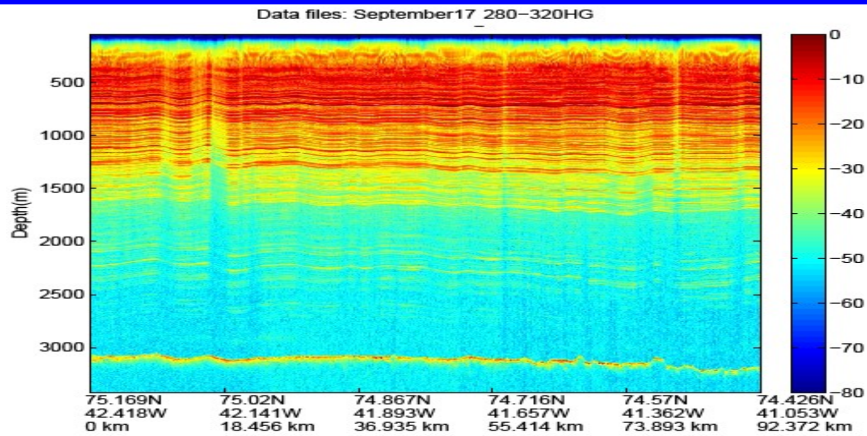
With laser on

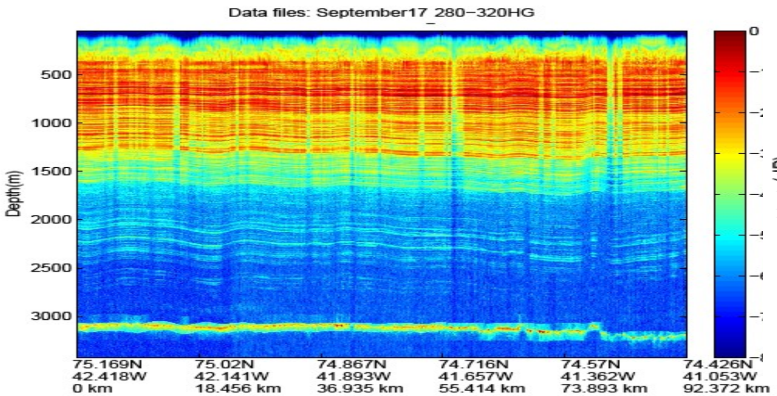


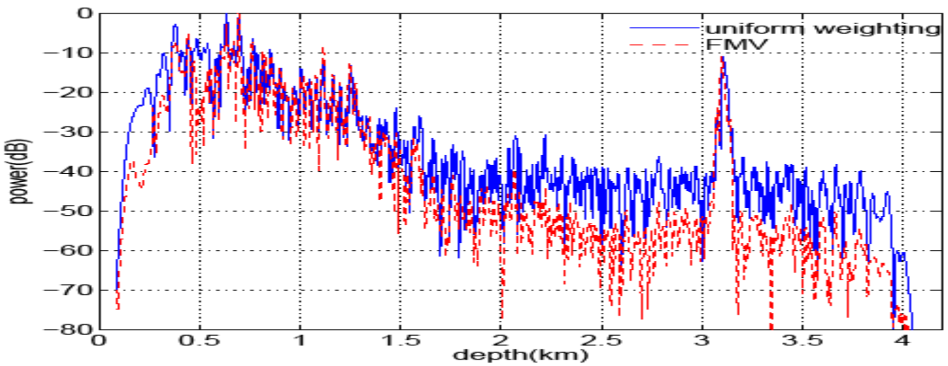
Laser off

RFI problem and solution

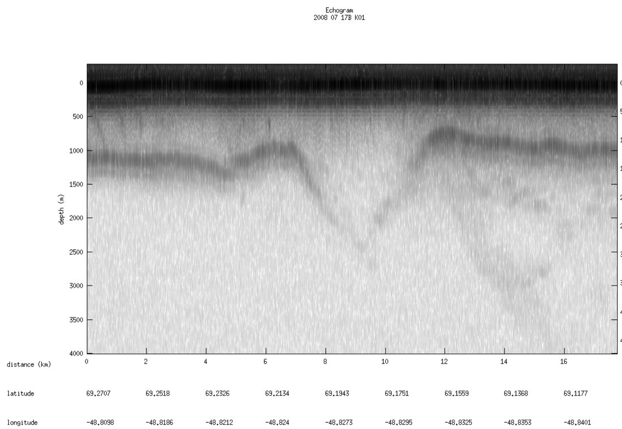


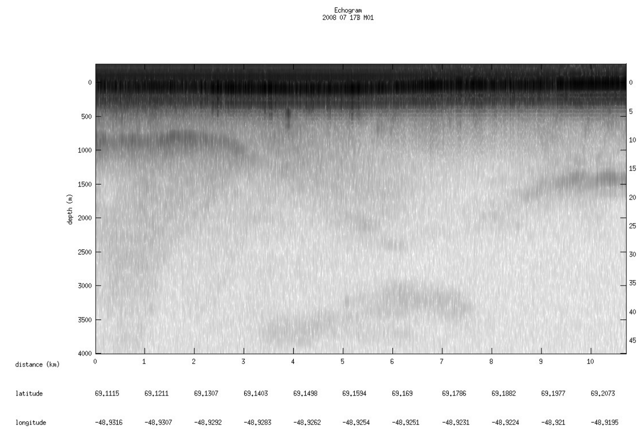


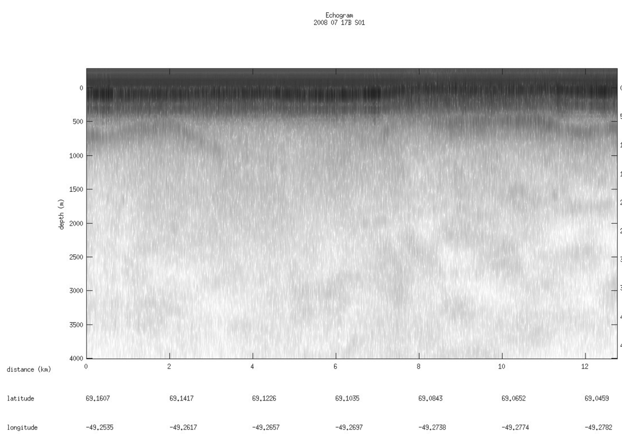


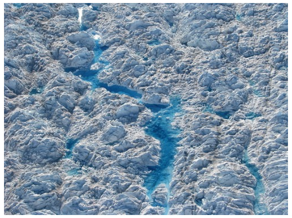


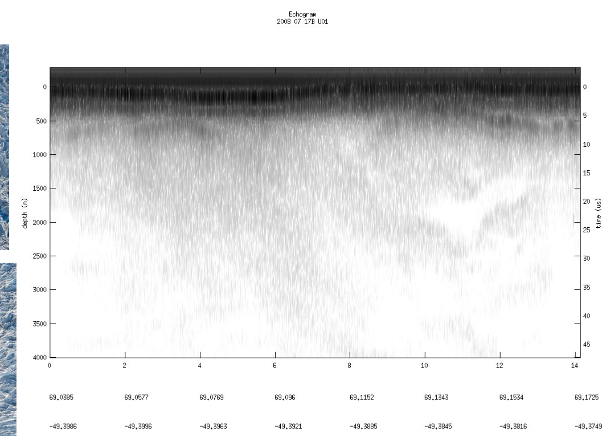
Narrow Bandwidth– to reduce RFI











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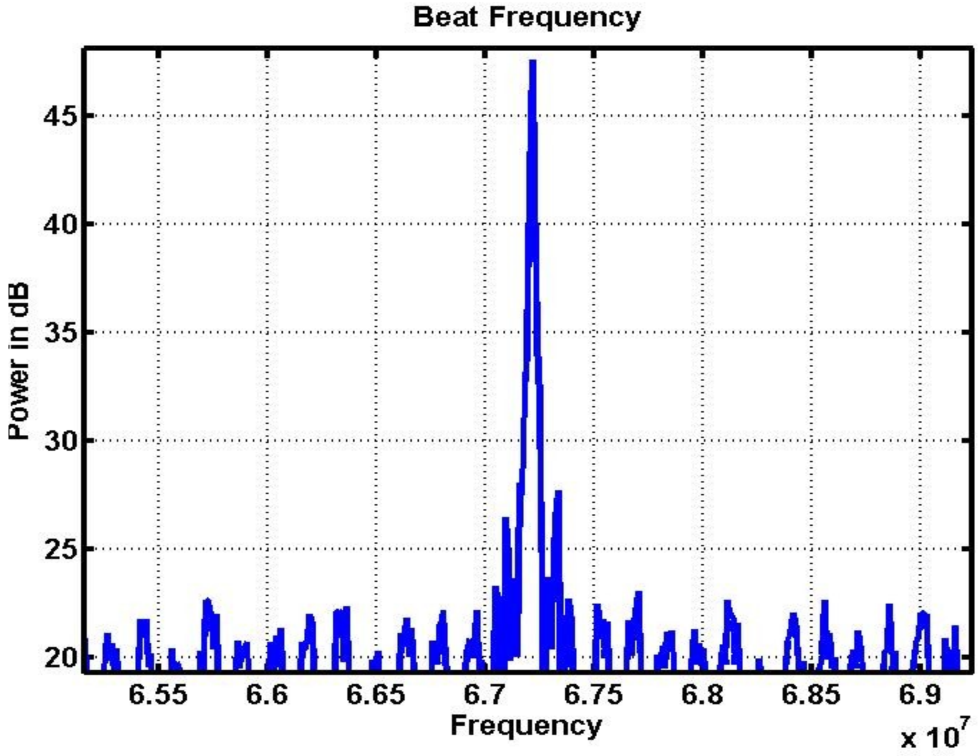
Ku-band Radar Altimeter

- To measure ice-surface elevation

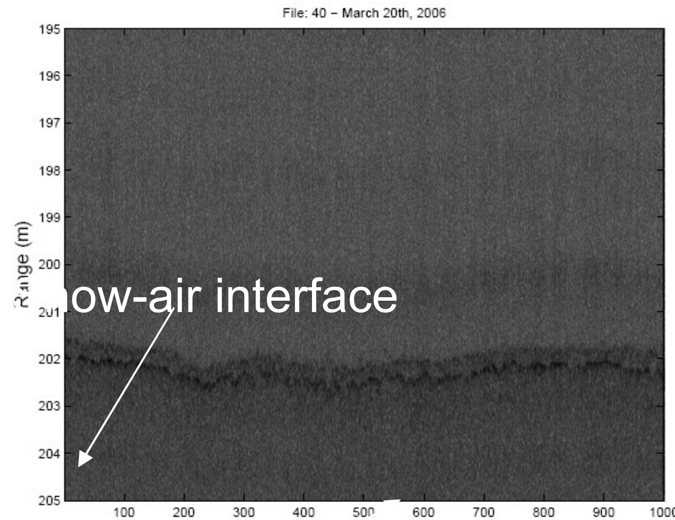
System	Ku-band Altimeter
Architecture	FM-CW
Frequency range	13-17 GHz
Output power	200 mW
Pulse duration	240 μs
Pulse repetition frequency	2.5 kHz
Antenna	2x Patch array
Max operational altitude	< 2 km
Nominal ground speed	250 m/s
Vertical resolution	~ 10 cm
Footprint *(varies with altitude)*	~ 5 m (along-track) ~ 30 m (cross-track)
Recording data rate	20 MB/s
On-board storage capacity	1 TB

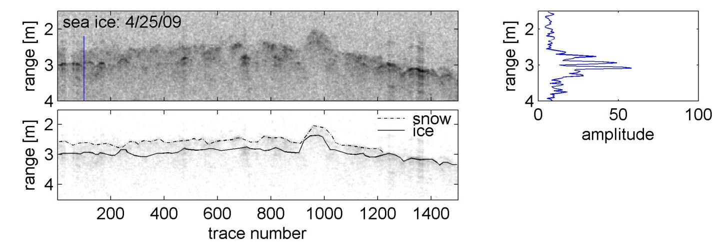


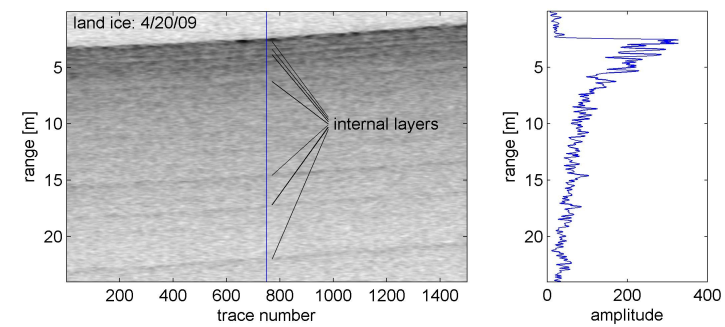
Snow Radar

- Ultra wideband radar

Parameter	Value	Units
Architecture	FM-CW	
Frequency range	2.5 – 7	GHz
Peak transmit power	< 1	W
Transmit pulse duration	270	μs
Pulse repetition frequency	2.5	kHz
Number of antennas in array	2 (Horn)	
Max operational altitude	< 600 m (snow thickness) < 2 km (altimetry)	
Nominal ground speed	250	m/s
Maximum ice thickness	5	km
Vertical resolution (in ice)	~ 10	cm
Footprint (varies w/ altitude)	~ 10	m (along-track)
Recording data rate	20	MB/s
On-board data storage capacity	1	TB







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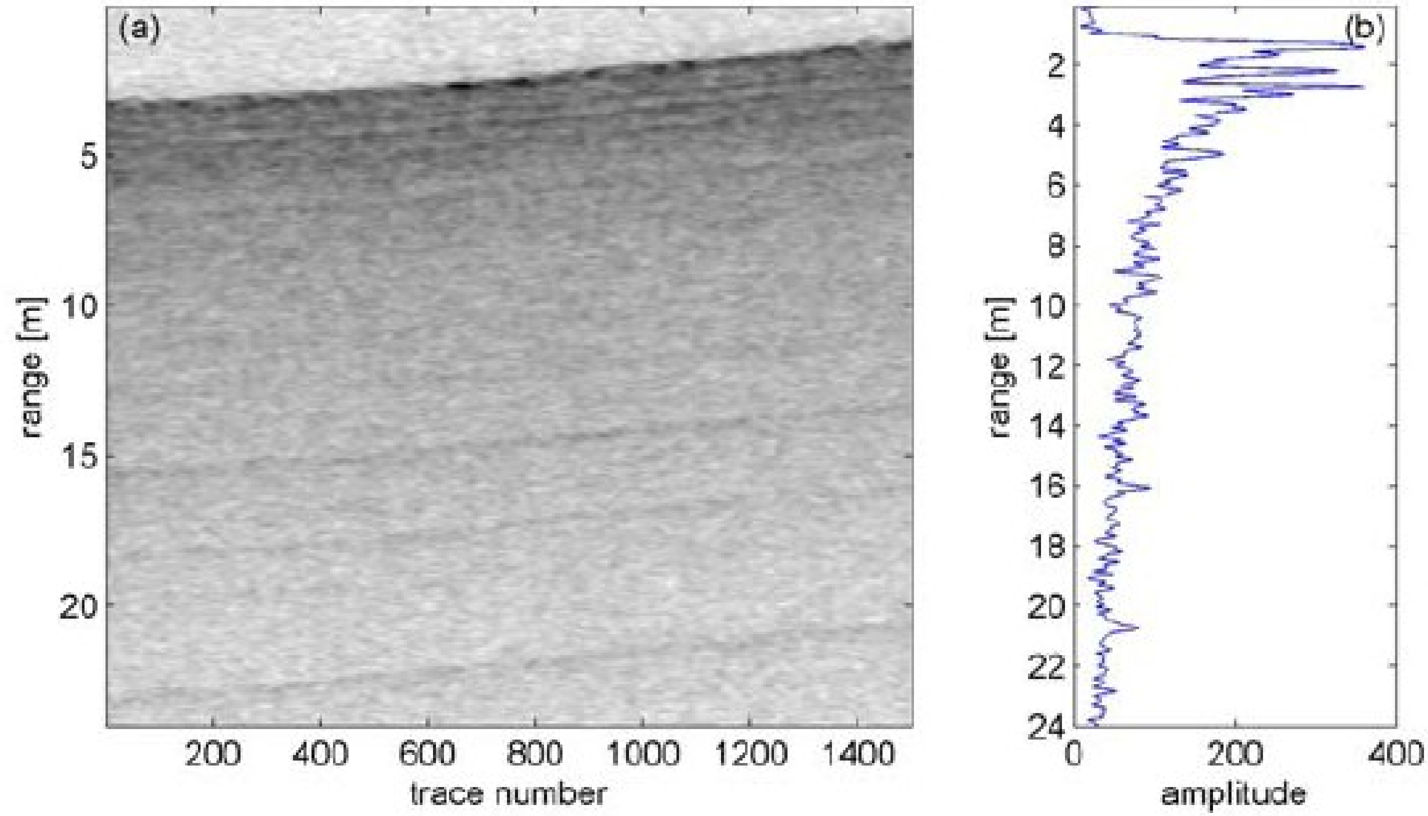
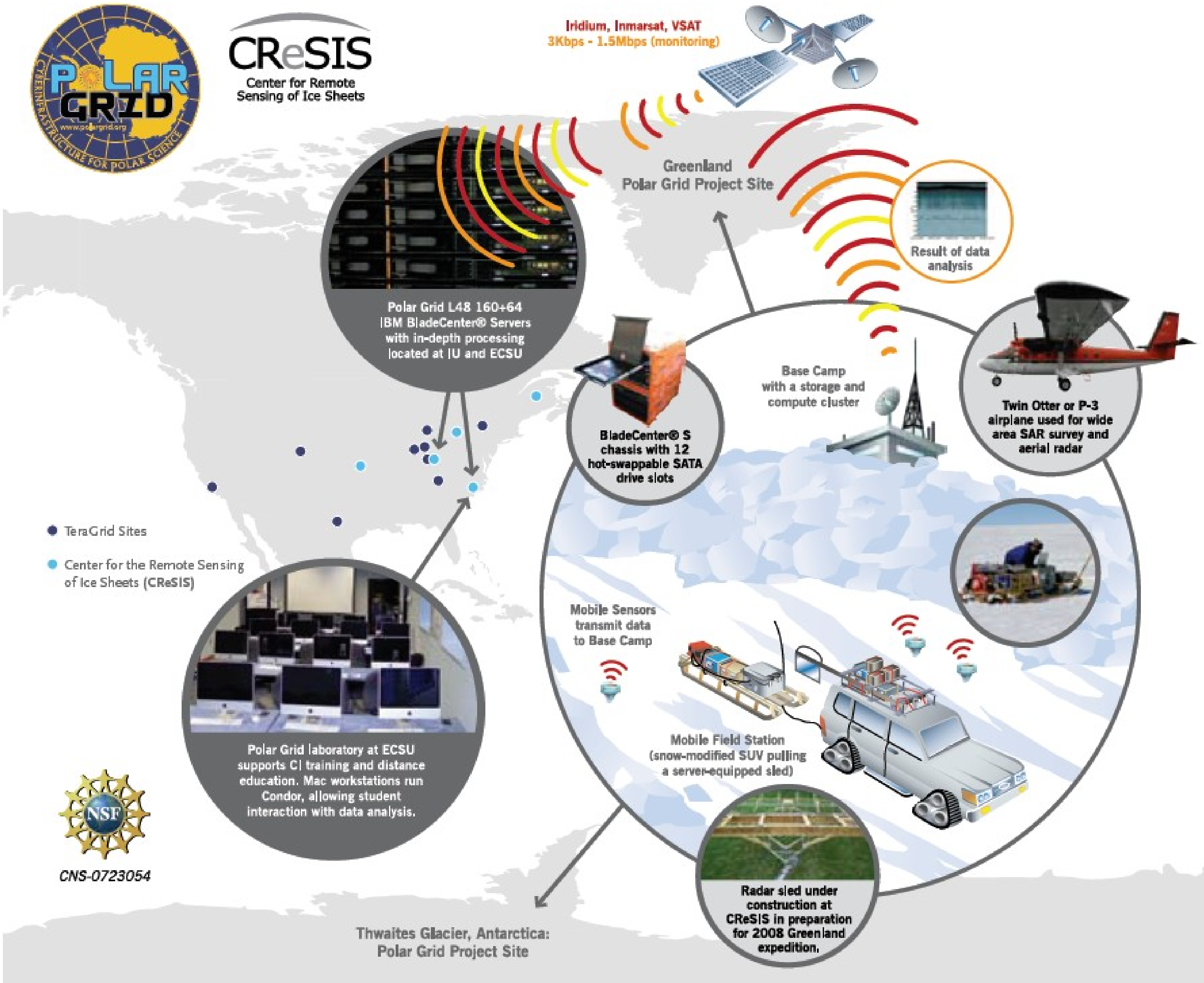
Snow Radar Data Over Firn




CReSIS
Center for Remote Sensing of Ice Sheets
Iridium, Inmarsat, VSAT
3Kbps - 1.5Mbps (monitoring)
Greenland
Polar Grid Project Site
Result of data analysis
Polar Grid L48 160+64
IBM BladeCenter® Servers
with in-depth processing
located at IU and ECSU
BladeCenter® S chassis with 12 hot-swappable SATA drive slots
Base Camp with a storage and compute cluster
Twin Otter or P-3 airplane used for wide area SAR survey and aerial radar
TeraGrid Sites
Center for the Remote Sensing of Ice Sheets (CReSIS)
Mobile Sensors transmit data to Base Camp
Mobile Field Station (snow-modified SUV pulling a server-equipped sled)
Polar Grid laboratory at ECSU supports CI training and distance education. Mac workstations run Condor, allowing student interaction with data analysis.
CNS-0723054
Radar sled under construction at CReSIS in preparation for 2008 Greenland expedition.
Thwaites Glacier, Antarctica:
Polar Grid Project Site

Data Processing

- On-site processing
  - 24-48 hours
- SAR and Array processing
  - 3 months after equipment returns to Lawrence
- RFI reduction algorithms and SAR images
  - 6-18 months

Summary

"I invented nothing new. I simply assembled into a car the discoveries of other men behind whom were centuries of work. . . Had I worked fifty or ten or even five years before, I would have failed. So it is with every new thing. Progress happens when all the factors that make for it are ready, and then it is inevitable. To teach that a comparatively few men are responsible for the greatest forward steps of mankind is the worst sort of nonsense. " Henry Ford

Importance of ice sheets and sea level rise

Technological advances

- **> Integration of analog and digital circuits on chips**
- **> CAD tools to design and optimize**
- **> Signal processing techniques**

Ability to handle large data sets

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National Science Foundation
WHERE DISCOVERIES BEGIN

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